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Lactate and pH evaluation in exhausted humans with prolonged TASER X26 exposure or continued exertion

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ABSTRACT

Objective: Safety concerns about TASER[®] Conducted Electrical Weapon (CEW) use and media reports of deaths after exposure have been expressed. CEWs are sometimes used on exhausted subjects to end resistance. The alternative is often a continued struggle. It is unclear if CEW use is metabolically different than allowing a continued struggle. We sought to determine if CEW exposure on exhausted humans caused worsening acidosis when compared with continued exertion.

Methods: This was a prospective study of human volunteers recruited during a CEW training course. Volunteers were from several different occupations and represented a wide range of ages and body mass index characteristics. Medical histories, baseline pH and lactate values were obtained. **Patients were assigned to one of four groups: 2 control groups consisting of Exertion only and CEW Exposure only, and the 2 experimental groups that were Exertion plus CEW Exposure and Exertion plus additional Exertion.**

Blood sampling occurred after Exertion and after any CEW exposure. This was repeated every 2-min until 20 min after protocol completion. Descriptive statistics were used to compare the four groups. The experimental groups and the control groups were compared individually at each time point using Wilcoxon rank sum tests. Lactate and pH association was assessed using multiple linear regression.

Results: Forty subjects were enrolled. There were no median pH or lactate differences between CEW Exposure groups at baseline, or between Exertion protocol groups immediately after completion. The CEW Exposure only group had higher pH and lower lactate values at all time points after exposure than the Exertion only group. **After completing the Exertion protocol, there was no difference in the pH or lactate values between the continued Exertion group and the CEW Exposure group at any time points.**

Conclusion: Subjects who had CEW Exposure only had higher pH and lower lactate values than subjects who completed the Exertion protocol only. CEW exposure does not appear to worsen acidosis in exhausted subjects any differently than briefly continued exertion.

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1. Introduction

The Conducted Electrical Weapon (CEW) is currently available for law enforcement and it is designed to subdue or repel agitated or violent individuals. It has come under scrutiny by national and international media and human rights organizations because there have been unexpected deaths of persons in custody following its use [1,2]. Although most deaths in law enforcement custody occur

when no CEW has been applied (70%) [3,4], a causal association has been suggested in the lay press [5–7]. This association is largely made due to time proximity of CEW application and death. Theories about this association have included production of immediate fatal arrhythmias or some type of delayed organ system damage that manifests itself as sudden death at a later time period [8]. Previous work in this area has not demonstrated a clinically dangerous effect on human volunteers [9–14].

The CEW is often applied to subjects in the field who have physically exerted and exhausted themselves just prior to the application and may continue to exert themselves throughout the arrest and control process. This exhaustion may be due to profound agitation, or fleeing from and resisting law enforcement. Intense struggling is an activity that has been associated with sudden custodial arrest-related death (ARD) [15]. Acidosis is a condition that

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has also been associated with death in this population [16]. It is believed that the acidosis is due to several factors including use of illicit stimulants in this population and continued fleeing, fighting or resisting law enforcement authorities [17,18]. There is controversy surrounding the use of a CEW in this subject population.

There is animal data to suggest that CEW exposure to rested animals under laboratory conditions can lead to worsening acidosis [19]. The effect of a CEW on pH immediately after its application has been reported but the effect over the subsequent short-term period following application has not [13]. It is not known what the effect of a CEW is on an exhausted subject's metabolic physiology during this short-term period after exposure.

The first objective of this study was to determine the pH and lactate changes in the 20 min after a CEW exposure, and to compare them to the effects of the Exertion protocol used in this experimental model. Determining this would allow comparison of this model to previous human studies that have not obtained short-interval acidosis measurements during this time period. The next objective was to determine the metabolic effect of a prolonged CEW exposure in exhausted and rested subjects in the 20 min immediately following exposure, and to compare this to subjects who continued to exert themselves but were not exposed to a CEW. Our null hypothesis was that there would be no difference in the pH or lactate at any time point in exhausted subjects who were exposed to a CEW than in exhausted subjects who continued to exert themselves.

2. Material and methods

2.1. Study design

This was a prospective study of adult volunteers recruited at a TASER International training course in August, 2008. The institutional review board of Hennepin County Medical Center approved the study. All subjects provided informed consent before enrollment. This study received partial funding from TASER International in the form of an unrestricted research grant that covered the cost of phlebotomy and laboratory services. The study sponsor had no role in designing the study, collecting the data, analyzing the data, writing the manuscript or submitting it for publication.

2.2. Study setting and population

This study was performed with volunteer human subjects attending a training course. As a voluntary part of their training course, they were to receive a CEW exposure from a TASER device. All adult subjects (age > 18 years) who were going to receive this exposure were eligible for enrollment in the study. Volunteers were personnel involved in various occupations including: medicine, sales, law enforcement, corrections, public relations, public utility maintenance, long-haul transportation and political campaign management. They did not have to participate in the study as a requirement for successful course completion but declining to participate in the study did not absolve them from receiving a CEW application as part of the training course. The exclusion criteria were known pregnancy and persons with known mental illness diagnoses. Volunteers were given a TASER CEW upon successful completion of the study protocol.

2.3. Study protocol

All volunteers completed a medical questionnaire that included: age, gender, occupation, body mass index (BMI) parameters, past medical history, current medication use, and history of recent heavy exertion. After completion of the study questionnaire, all volunteers had an 18 or 20 gauge intravenous catheter placed in an upper extremity and had blood drawn from this for baseline analysis of venous pH and lactate.

Upon completion of the baseline blood analysis, each volunteer was randomly placed into 1 of 4 study groups. Randomization was accomplished by having volunteers present themselves for testing on a first come, first served basis and then cycling them through the next available testing group station. The groups were: group 1 – Prolonged CEW Exposure protocol only without exertion; group 2 – Exertion protocol only; group 3 – Exertion protocol followed by Prolonged CEW Exposure protocol; and group 4 – Exertion protocol followed by Additional Exertion Protocol. Detailed explanation of the group protocols are as follows:

2.3.1. Exertion protocol (groups 2, 3, 4)

After informed consent and baseline blood sampling, volunteers that were placed into groups 2–4 performed a series of intense, rigorous physical activities

designed to invoke anaerobic exhaustion. This activity began with a 30-s timed period of push-ups. The volunteer was instructed to perform as many push-ups as they were able to during this time period. If they could not continuously perform push-ups for the 30-s duration, they were allowed to rest in the “up” position (arms at full extension, feet in contact with the floor) until they could continue. Immediately (defined as within 5 s) following the push-ups, the volunteer ran on a treadmill that was moving at 8.0 miles per hour at 8 degrees of elevation. They were instructed to run until they could no longer keep up with the pace of the treadmill. Subjects were instructed to step off the treadmill at that time. At this point, they were defined as being subjectively exhausted and immediately (within 45 s) underwent blood sampling from their intravenous catheter for repeat pH and lactate evaluation. Total time (minutes:seconds) of exertion was recorded for volunteers in these groups.

2.3.2. Prolonged CEW Exposure protocol (groups 1, 3)

Volunteers that were selected into groups 1 and 3 received a prolonged CEW application. Group 1 volunteers received the Prolonged CEW Exposure protocol only with no prior exertion (they were in a rested state at time of CEW exposure). Group 3 volunteers received the Prolonged CEW Exposure protocol immediately after completing the Exertion protocol.

The Prolonged CEW Exposure protocol consisted of a 15 s application with applied electrodes powered by a TASER X26 CEW (TASER International, Scottsdale, AZ). The exposure consisted of manually applying electrodes to the volunteer while they were lying on a padded mat in a supine position. The electrodes were manually placed and taped into position within conductive gel instead of being fired from the CEW at the subject to assure exact placement from volunteer to volunteer. The electrodes were placed on the subject's trunk in ipsilateral, anterior thorax positions to span a majority of the trunk while including trans-diaphragmatic positioning. The electrodes were always placed on the side of the thorax opposite that of the extremity that the intravenous catheter was placed in order to avoid catheter displacement in the event of upper extremity contraction during the event. Placement was always in the mid-pectoral region for the superior electrode and at the waistline for the inferior electrode in a vertical position (Fig. 1).

The TASER X26 CEW internal software had a single modification that allowed the exposure duration to run for a continuous 15 s of duration with each pull of the trigger (a standard TASER X26 CEW trigger pull yields a 5 s run duration). No other modification was made to the CEW. The purpose of the software modification was to enable the CEW current application to be delivered in an objective, reproducible and controlled fashion. With the exception of this, the CEW was not altered from the factory standard. Immediately following the CEW application (within 45 s), all subjects had blood sampled by the investigators.

2.3.3. Additional Exertion Protocol (group 4)

Following completion of the Exertion protocol and the subsequent blood sampling, the subjects in group 4 underwent an additional 1-min of running on the treadmill at 8 miles per hour and 8 degrees of elevation. Subjects were instructed to stop if they became too exhausted to keep up with the treadmill prior to 1 min. Upon completing this additional period of exertion, the subject immediately (within 45 s) had blood sampled and was allowed to recover in a sitting or semi-recumbent position.

2.3.4. Universal protocol (all groups)

All subjects in all 4 groups had an 18 or 20 gauge venous catheter placed into an upper extremity at the start of the investigation so that serial venous blood samples could be taken at various times during the study period. Intravenous catheter insertion was performed by either a certified paramedic or one of the physician investigators. After each blood sample was drawn, the specimens were labeled and analyzed immediately on a portable I-STAT[®] point of care analyzer using a CG4+ analysis cartridge (Abbott Diagnostics, Abbott Park, IL). The blood samples were analyzed for pH and lactate. Blood sampling occurred universally at 2-min intervals after the final stressor event (either final exertion event or CEW exposure) was completed. The blood sampling continued until 20 min after the final stressor event. Following the completion of the blood sampling, all subjects were allowed to recover in a sitting or semi-recumbent position, the intravenous catheter was removed aseptically, the area was bandaged, and the subject was offered a light snack and oral hydration.

2.4. Data analysis

Data were entered in an Excel (Microsoft Excel 2008, Redmond, WA) spreadsheet for analysis. Data analysis was performed using STATA 10.0 (STATA Corp., College Station, TX). Descriptive statistics were used where appropriate. Values at time points were compared between groups 1 and 2 and between groups 3 and 4 using Wilcoxon rank sum tests. The association between pH and lactate over time within and between the exposure groups was assessed using multiple linear regression. Power analysis of the Wilcoxon rank sum test revealed that in order to detect a 10% difference between lab values at the post-exposure time point, with a significance of 0.05 and a power of 80%, 9 subjects were required in each group.

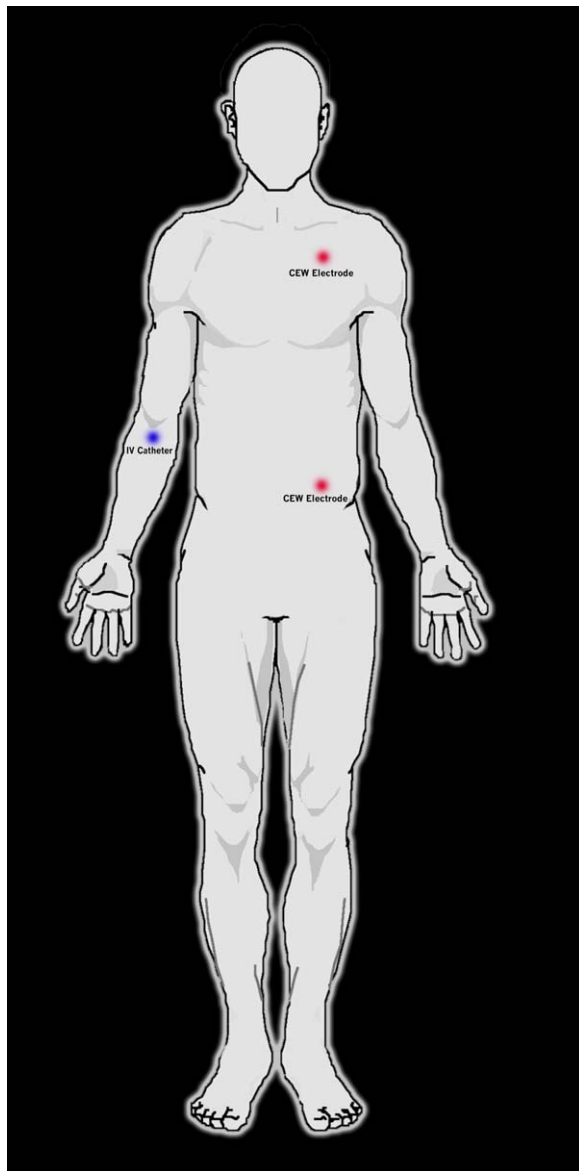


Fig. 1. Electrode placement example (ipsilateral, anterior thorax at mid-pectoral area and waistline on the side opposite of the IV catheter).

3. Results

There were 40 subjects enrolled, 10 in each group. Subject demographics are in Table 1. All post-exertion and post-CEW exposure blood draws were completed within 45 s of exertion or

exposure conclusion. There was 1 volunteer in group 4 that did not complete the full minute of additional treadmill exertion at the discretion of the lead investigator due to fatigue. For this volunteer, the treadmill was shut down at 57 s upon noticing that the study subject was experiencing difficulty in keeping up with the treadmill and there was a safety concern when the study subject nearly fell. There were no adverse events that occurred related to this study.

Tables 2 and 3 and Figs. 2–5 display pH and lactate values at all time points. There were no differences between the groups at baseline. The CEW Exposure only group had higher values of pH and lower values of lactate at all time points after the CEW Exposure than the Exertion only group. There were no differences in groups 3 and 4 immediately after the Exertion protocol was completed. After the Exertion protocol, the Additional Exertion group showed no difference in median pH or median lactate than the CEW Exposure group at any time point. Multiple linear regression demonstrated that change in pH did not correlate with the groups over time (coefficient 0.001, 95% CI –0.0001 to 0.003, $p = 0.21$) but change in lactate did (coefficient 0.30, 95% CI 0.21–0.40, $p < 0.001$).

4. Discussion

CEWs are categorized as non-lethal weapons by the United States Department of Defense and offer law enforcement personnel an option for control of agitated or potentially violent persons [20]. CEWs have become increasingly popular tools of force used by law enforcement and corrections personnel and are considered by most agencies to be in a class known as an intermediate weapon. Intermediate weapons are devices that generally can induce subject compliance due to pain or incapacitation and are more than the use of “empty-hand” control techniques but less than deadly force devices. Examples of intermediate weapons include aerosolized chemical irritants, impact batons, and projectile beanbags.

This project utilized the TASER brand of CEW. TASER® is an acronym for Thomas A. Swift’s Electric Rifle and is a name based on a fictional series of children’s literature. Our work focused on the TASER X26 model of CEW because it is currently the most popular handheld law enforcement CEW in use and is the model most likely to be encountered in the field. The X26 is programmed to deliver a roughly rectangular pulse of approximately 100 μ s duration with about 100 μ C of charge at 19 pulses per second for 5 s [21]. The peak voltage across the body is approximately 1200–2400 V but the weapon also develops an open circuit arc of 50,000 V to traverse clothing in cases where no direct contact is made. The average current is approximately 2.1 mA. It uses compressed nitrogen to fire 2 metallic darts up to a maximum of 35 feet with a pre-determined angled rate of spread. When it makes adequate contact and the darts are of adequate separation, it causes involuntary contractions of the regional skeletal muscles that render the subject incapable of

Table 1
Volunteer demographics.

	Group 1 (CEW only)	Group 2 (Exertion only)	Group 3 (Exertion + CEW)	Group 4 (Exertion + Exertion)	Total
Number	10	10	10	10	40
# Females	3	4	2	1	10
BMI (median, range)	22.9, 16.6–35.4	28.1, 20.4–47.3	27.6, 19.7–28.9	27.1, 22.4–54.8	26.0, 16.6–54.8
Past medical history	1 asthma 1 high cholesterol	1 high cholesterol 1 hypertension	None	1 high cholesterol 1 left bundle branch block	
Medication	1 albuterol/advaair 1 statins	1 statin 2 synthroid 1 diuretic	None	2 statins	
Recent exertion	2/10	4/10	2/10	4/10	12/40
Median age in years (range)	38, 22–54	32, 20–46	35, 20–44	36.5, 20–49	

Table 2
pH.

	Group 1, CEW only (median, range)	Group 2, Exertion only (median, range)	Wilcoxon rank sum (group 3 vs. 4)
Baseline	7.37, 7.29–7.40	7.35, 7.29–7.40	0.724
Immediately after exertion	–	7.13, 7.03–7.34	
Immediately after CEW/2nd exertion	7.35, 7.30–7.39	–	
2 min after CEW/2nd exertion	7.33, 7.26–7.39	7.07, 7.04–7.15	<0.001
4 min	7.35, 7.27–7.40	7.10, 7.06–7.14	<0.001
6 min	7.34, 7.31–7.41	7.11, 7.05–7.30	<0.001
8 min	7.35, 7.32–7.42	7.13, 7.07–7.28	<0.001
10 min	7.37, 7.35–7.40	7.14, 7.05–7.30	<0.001
12 min	7.37, 7.34–7.40	7.17, 7.00–7.32	<0.001
14 min	7.37, 7.34–7.39	7.18, 7.07–7.33	<0.001
16 min	7.38, 7.34–7.40	7.20, 7.09–7.31	<0.001
18 min	7.38, 7.33–7.40	7.22, 7.10–7.32	<0.001
20 min	7.38, 7.36–7.40	7.24, 7.13–7.30	<0.001
	Group 3, Exertion + CEW (median, range)	Group 4, Exertion + Exertion (median, range)	Wilcoxon rank sum (group 3 vs. 4)
Baseline	7.38, 7.32–7.41	7.36, 7.13–7.43	0.774
Immediately after exertion	7.19, 7.05–7.26	7.14, 6.95–7.39	0.653
Immediately after CEW/2nd exertion	7.12, 7.01–7.23	7.11, 6.98–7.26	0.791
2 min after CEW/2nd exertion	7.11, 7.01–7.25	7.09, 7.00–7.20	0.495
4 min	7.11, 7.00–7.25	7.10, 7.00–7.21	0.437
6 min	7.13, 6.99–7.26	7.08, 6.97–7.24	0.596
8 min	7.13, 7.01–7.28	7.12, 7.00–7.26	0.910
10 min	7.16, 7.22–7.31	7.15, 7.00–7.28	0.567
12 min	7.18, 7.02–7.34	7.17, 7.00–7.32	0.624
14 min	7.20, 7.05–7.36	7.19, 7.04–7.39	0.689
16 min	7.21, 7.06–7.36	7.20, 7.05–7.35	0.682
18 min	7.22, 7.10–7.38	7.25, 7.06–7.36	0.790
20 min	7.26, 7.10–7.36	7.25, 7.08–7.38	0.967

voluntary movement. If the darts are fired at very close range and do not achieve adequate separation, full muscular incapacitation may not be achieved and the device is then used to encourage certain behavior through pain compliance.

Agitated persons confronted by law enforcement have been associated with states of severe exhaustion and metabolic acidosis [16]. It is not clear whether this state of exhaustion, coupled with the application of a CEW might lead to adverse acidosis parameters

Table 3
Lactate (mmol/L).

	Group 1, CEW only (median, range)	Group 2, Exertion only (median, range)	Wilcoxon rank sum (group 3 vs. 4)
Baseline	1.6, 0.6–2.9	1.4, 0.7–3.0	0.597
Immediately after exertion	–	13.2, 5.7–17.8	<0.001
Immediately after CEW/2nd exertion	2.1, 1.8–3.3	–	<0.001
2 min after CEW/2nd exertion	3.6, 2.5–5.5	14.6, 10.4–18.3	<0.001
4 min	4.1, 2.5–5.3	13.0, 10.5–17.5	<0.001
6 min	4.5, 2.7–5.2	14.7, 10.0–18.1	<0.001
8 min	3.4, 2.3–5.3	14.5, 9.8–18.3	<0.001
10 min	3.4, 2.2–4.9	14.6, 8.8–17.9	<0.001
12 min	3.2, 1.7–4.5	13.2, 8.7–17.2	<0.001
14 min	2.9, 1.8–4.1	12.5, 8.1–16.5	<0.001
16 min	2.7, 1.7–3.8	12.0, 7.8–18.9	<0.001
18 min	2.6, 1.5–3.6	11.9, 7.3–18.6	<0.001
20 min	2.0, 1.3–3.3	11.3, 2.0–17.7	<0.001
	Group 3, Exertion + CEW (median, range)	Group 4, Exertion + Exertion (median, range)	Wilcoxon rank sum (group 3 vs. 4)
Baseline	1.3, 0.9–1.7	1.6, 0.7–3.4	0.270
Immediately after exertion	9.1, 6.1–13.1	10.2, 0.9–18.1	0.165
Immediately after CEW/2nd exertion	11.6, 7.8–15.0	12.7, 8.0–18.2	0.821
2 min after CEW/2nd exertion	16.0, 10.4–20.0	16.0, 10.9–19.2	0.734
4 min	16.7, 10.3–20.0	16.1, 10.0–19.5	0.935
6 min	16.4, 10.2–19.8	15.4, 10.5–20.0	0.706
8 min	15.6, 9.7–19.1	15.3, 10.6–19.3	0.880
10 min	15.3, 9.4–19.4	14.6, 9.6–20.0	0.807
12 min	15.4, 8.2–18.9	14.5, 9.1–20.0	0.722
14 min	19.5, 7.9–18.8	14.1, 8.5–20.0	0.832
16 min	13.9, 7.5–18.3	13.3, 7.8–18.9	1.000
18 min	13.0, 6.7–17.5	11.9, 7.3–18.6	0.683
20 min	12.3, 6.1–17.6	11.3, 7.0–17.7	0.929

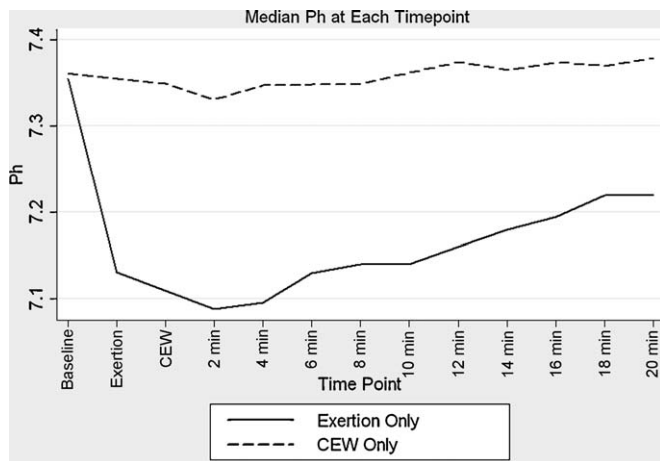


Fig. 2. Median pH of control groups.

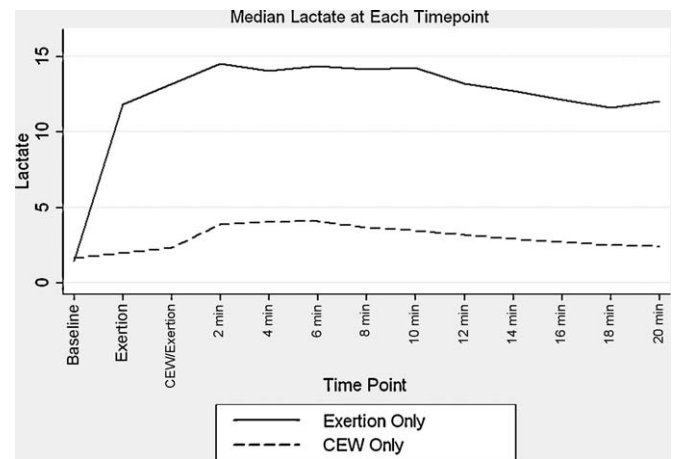


Fig. 4. Median lactate of control groups.

shortly after application. This study was designed primarily to examine what the physiologic differences are in terms of acidosis between ending a situation with a prolonged CEW exposure versus allowing a person to continue on with their resistive behavior. It has been theorized that the application of a CEW on an already acidotic person could potentially lead to a worsening acidosis condition that causes death. Prior work in this area by Ho et al. has examined exhausted human subjects that received prolonged CEW exposures and reported biomarkers for acidosis immediately (within 1 min) following the exposures and 16–24 h after CEW exposure [13]. However, the time period following the first minute after CEW exposure has not been specifically examined. The lack of information for this short window of time partially led to a recent successful argument that CEW application likely worsened acidosis and caused an ARD within this short window of time [22]. However, our current work in this area specifically attempts to address this previously unstudied time frame.

We found that when applying a CEW to an acidotic subject, this short-term interval is not physiologically worse with regard to acidosis parameters than allowing the subject to continue with their exertional activity. This is an important finding because law enforcement authorities in a situation requiring them to immediately intervene generally have 1 of these 2 choices available to them (immediately stopping the resistance through incapacitation with a CEW or using time consuming control techniques that rely on pain such as pepper spray or “hands-on” methods that allow the subject to continue to resist, fight or flee).

Because the goal of this project was to address CEW application in acidotic subjects undergoing restraint, it was important for us to attempt to reproduce the conditions of acidosis that are present in the field during an interaction with law enforcement. We considered exercising our volunteers to 85% of maximal predicted heart rate as this exercise protocol is widely used for physical fitness training but decided against this because we were not attempting to evaluate fitness. We designed our Exertion protocol to induce intense anaerobic exhaustion over a short period of time, a time situation that we believe is similar to the dynamic field conditions faced by law enforcement authorities. In this study, subjects exerted themselves to subjective exhaustion. We have used this Exertion protocol in a prior study [13]. Subjects were instructed to perform the Exertion protocol event until they perceived themselves to be exhausted. Their level of exhaustion was objectively measured by their venous pH status immediately before and after the event. We believe that this allowed us to truly test for the effect that exhaustion has when coupled with CEW application. In reality, an agitated person with delirium or intoxication is likely able to ignore their internal cues of exhaustion that our non-impaired volunteers heeded. This could lead to severe anaerobic exhaustion as the subject vigorously fights, flees and resists any efforts to attempt to control them.

Anaerobic exhaustion and metabolic acidosis are generally measured by serum pH and lactate values [23]. We elected to use venous pH as a measurement of acid/base balance in the volunteers. Although arterial sampling is often thought of as

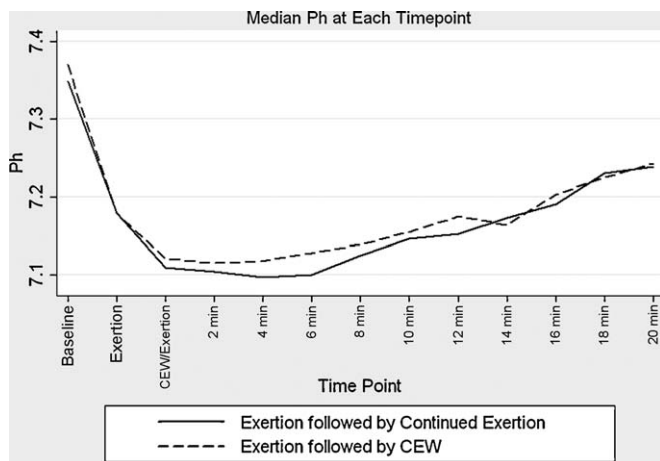


Fig. 3. Median pH of experiment groups.

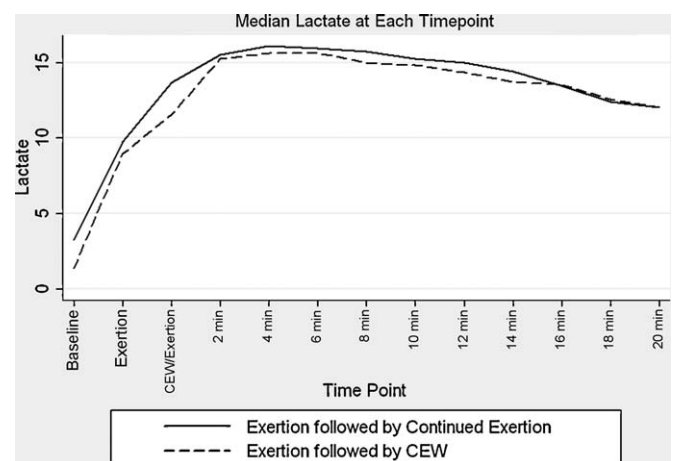


Fig. 5. Median lactate of experiment groups.

the “gold standard” for pH measurement, current literature indicates that there is good correlation for pH values between arterial and venous samples [24–26]. Electing to utilize a venous sample in this experiment allowed us to place a peripheral venous sampling catheter that was more comfortable for our volunteers instead of having to perform a more painful percutaneous arterial puncture or undergo an indwelling arterial catheter placement.

We found that utilizing a CEW in this simulated study situation was no worse than allowing the subject to briefly continue exerting themselves (for 1 min) from an acid/base physiology standpoint. The effect of allowing a subject to continue prolonged exertion beyond 1 min is unknown. Exposure to a CEW alone did not induce acidosis similar to exertion, and exhausted subjects did not show a difference in pH or lactate whether they exerted themselves or not for an additional minute, or were exposed to a CEW. Because exhausted subjects are associated with ARD, it may be intuitively safer to use a device such as the CEW that could quickly end a prolonged struggle instead of allowing an exertional struggle to continue unabated.

It is important to note that in group 4 (Additional Exertion Protocol), the goal was to simulate what occurs in a realistic scenario when an agitated subject has a prolonged and exhaustive struggle with law enforcement authorities. We believe that the initial period of exhaustion simulated by our Exertion protocol demonstrates that a state of anaerobic exhaustion quickly occurs. The Additional Exertion Protocol was meant to simulate the continued resistive and hypermetabolic behavior that is often exhibited by subjects unless forced to stop through CEW application or chemical sedation. It is our experience and belief that in field encounters with law enforcement officials, continued resistive behavior by agitated subjects generally lasts much longer than a period of 1 min. However, for the purposes of this study, 1 min was the pre-determined limit to ensure the safety of the study volunteers. We believe that had the volunteers been able to continue exerting themselves beyond 1 additional minute, that our findings would demonstrate a worsening acidosis that is different and more severe than what was demonstrated by prolonged use of a CEW. In a subsequent study by Jauchem et al., blood pH and lactate were significantly changed after only three 5-s applications of a CEW. In that study, however, animals were also anesthetized [27].

There has been controversy about animal model studies that demonstrate CEW induced acidosis in rested swine [19,28]. CEW critics have pointed out that these studies are reasonable proof that a human being in an exhausted condition should exhibit significantly greater acidemia after CEW application [29]. We believe these animal studies need to be interpreted with caution. Both represent relatively unrealistic field CEW exposure durations (360 and 80 s respectively) and utilized animals that were deeply anesthetized and on life support ventilators without ability to compensate through respiratory mechanisms. In the Jauchem et al. study, complete cessation of breathing was noted during the CEW exposure time period. In the latter study, the ventilator was shut off during the exposure time period. Respiratory limitations in both studies would have artificially and significantly changed the acid/base physiology of the animal. This respiratory limitation has not been noted to occur in human research [30]. We believe Jauchem's cautionary statements to be correct in that they warn readers to not draw full conclusions between his study and real law enforcement use on humans due to methodology limitations [31]. Our data would also support Jauchem's statements since our findings in humans did not mimic his in swine.

The previous work by Ho et al. that demonstrates human subjects breathe above their baseline parameters during prolonged CEW application relates to our findings [30]. This is an important conclusion relative to our findings since continued ventilation at levels above baseline minute ventilation during CEW exposure of

an acidotic subject should only serve to improve an altered acid–base state. The demonstration by this study that CEW application to an exhausted cohort did not demonstrably worsen their acidotic condition has ramifications beyond simple acid–base physiology. Our data suggests that the modern day practice of utilizing a CEW to subdue or repel an agitated, exhausted individual may be a useful control option in this type of subject.

There was a significant increase in serum lactate that occurred following the Exertion protocol. This level also increased a small but statistically significant amount in volunteer group 3 and group 4. Lactate formation from exertion has been a classic explanation of acidosis and fatigue. However, a review by Robergs et al. demonstrates that lactate production increases only when there is an excess of cellular proton release with metabolism and its increase functions to supply the necessary nicotinamide adenine dinucleotide for glycolysis [32]. Therefore, increased lactate coincides with cell acidosis and remains a good marker for this condition but does not necessarily cause the acidosis to occur. Since lactate is a marker of exercise, exertion and metabolism, the elevations seen after exertion and after CEW exposure causing skeletal muscle activation were expected.

5. Limitations

A limitation of this study is that our study population did not exactly mimic the characteristics of human subjects that tend to have custodial death events. Literature indicates that in custodial death situations, the persons who die tend to have mental illness with psychotic features or illicit stimulant abuse histories [4]. These factors were presumably not present in our volunteer population. However, we do not believe that this limit equates to a “healthy population bias”. The volunteers that we studied were not young, did not have exceptional levels of physical fitness, and were made up of a variety of people in various occupations. They had a wide age range and some had medical problems that required controlling medication. Additionally, their average body mass index calculations place them in the “overweight” category by federal standards and does not suggest a superior level of fitness [33]. While our study population most likely did not have a history of psychosis or chronic illicit stimulant abuse, which are common descriptors of persons who die suddenly in custody, they do appear to represent the average adult citizen of this country [34]. It should also be noted that our data may not apply to situations of longer-duration CEW exposures or repetitive or numerous repetitive discharges beyond what we have studied [35,36].

An additional limitation is the possibility that the randomization process did not result in an equal distribution of volunteer demographics across all 4 groups of the study. Specifically, group 1 had a lower age grouping and BMI than the other 3 groups. We do not believe that this affects the results based on our prior work where we have exposed older and higher BMI subjects to a solitary CEW exposure while evaluating metabolic markers and have seen similar results [12].

6. Conclusion

Subjects who were exposed to the CEW but did not undergo the Exertion protocol had a higher pH and lower lactate than the exhaustion group at all time points after the baseline. **CEW exposure does not appear to worsen acidosis in exhausted, acidotic subjects differently than continued exertion.**

Contributions

Jeffrey Ho contributed to the study concept and design, acquisition of the data, drafting of the manuscript, critical revision

of the manuscript for important intellectual content, obtained funding, administrative, technical, or material support, and study supervision.

Donald Dawes contributed to the study concept and design, acquisition of the data, critical revision of the manuscript for important intellectual content, administrative, technical, or material support, and study supervision.

Jon Cole contributed to the acquisition of the data and administrative, technical, or material support.

Julie Hottinger contributed to the acquisition of the data and administrative, technical, or material support.

Ken Overton contributed to the acquisition of the data and administrative, technical, or material support.

James Miner contributed to the study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, statistical expertise, and study supervision.

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